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THE FLUTING AND PITTING OF GRANITES IN THE TROPICS.

(PLATES I–VIII.)

BY J. C. BRANNER.

(*Read April 4, 1913.*)

Fluting is a peculiar minor form of topographic relief, but where it occurs over an area large enough to attract attention, it is a very striking feature.

All geologists are familiar with the fluting of limestones, which is a common phenomenon all the world over. Many fine examples of the fluting of limestones are given in Dr. H. Stille's "Geologische Charakterbilder," 10 Heft, published at Berlin in 1912, in which they are called "Karren."

But the fluting of granites or of other crystalline rocks is, so far as I have been able to learn, confined to tropical, and possibly subtropical countries. Two cases that occur on the coast of the state of Pernambuco in Brazil were mentioned by me in a paper on rock decomposition published in 1896.[1] Since that paper was published I have seen in Brazil some very striking examples, and have seen photographs of several others. Good examples are also cited by Max Bauer, who speaks of them as furrows (Rillen).[2]

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[1] J. C. Branner, "Decomposition of Rocks in Brazil," *Bul. Geol. Soc. Amer.*, VII., 280, Rochester, 1896.

[2] *Neues Jahrbuch f. Mineralogie*, 1898, II., 192, and Plate XI.

PROC. AMER. PHIL. SOC. LII. 209 K, PRINTED JUNE 6, 1913.

The cases mentioned by Bauer occur in granites at Point Larue on the Island of Mahé, one of the Seychelle Islands in the Indian Ocean, about latitude 4° 30′ south, and longitude 55° east.

The most impressive examples of the fluting of crystalline rocks that I have ever seen were found in 1911 near the village of Quixadá in the interior of the state of Ceará, Brazil (Plate I.), latitude 5° 5′ south and longitude 19° 20′ west at an elevation of 180 meters above tide. In the vicinity of Quixadá almost every elevated exposure of the granites shows more or less fluting. Only those of which the best photographs were obtained are shown in the accompanying plates. The hills shown in these pictures are from 100 to 225 meters high, that is above their bases. Efforts to get photographs of the fluting about Quixadá have been only partially successful, as may be seen from the illustrations given with the present paper. Horace E. Williams of the Serviço Geologico do Brazil has sent me a photograph of fluted granites in the Serra de Borborema, 25 kilometers south of Campina Grande in the state of Parahyba.

Other cases that have come to my attention occur in the interior of Ceará, and about the famous Itatiáya, the loftiest peak in Brazil, situated in the extreme northwest corner of the state of Rio de Janeiro. Itatiáya has an elevation of 2,994 meters above tide. The fluting of that peak was mentioned to me many years ago by Mr. Derby, the present director of the geological survey of Brazil,[3] but I did not then fully realize the extent and amount of it.

Recently I received from Dr. Carlos Moreira, of the National Museum at Rio de Janeiro, some photographs made by him of the Itatiáya peaks together with specimens of the rocks themselves. Dr. Moreira spent some forty-five days on and about that peak, and though his photographs are small, they are clear, and they are the best we have thus far seen of the fluting in that particular region (Plate II.).

CHARACTERISTICS OF THE FLUTING OF GRANITES.

In the fluting of limestones there is generally left at the crest of

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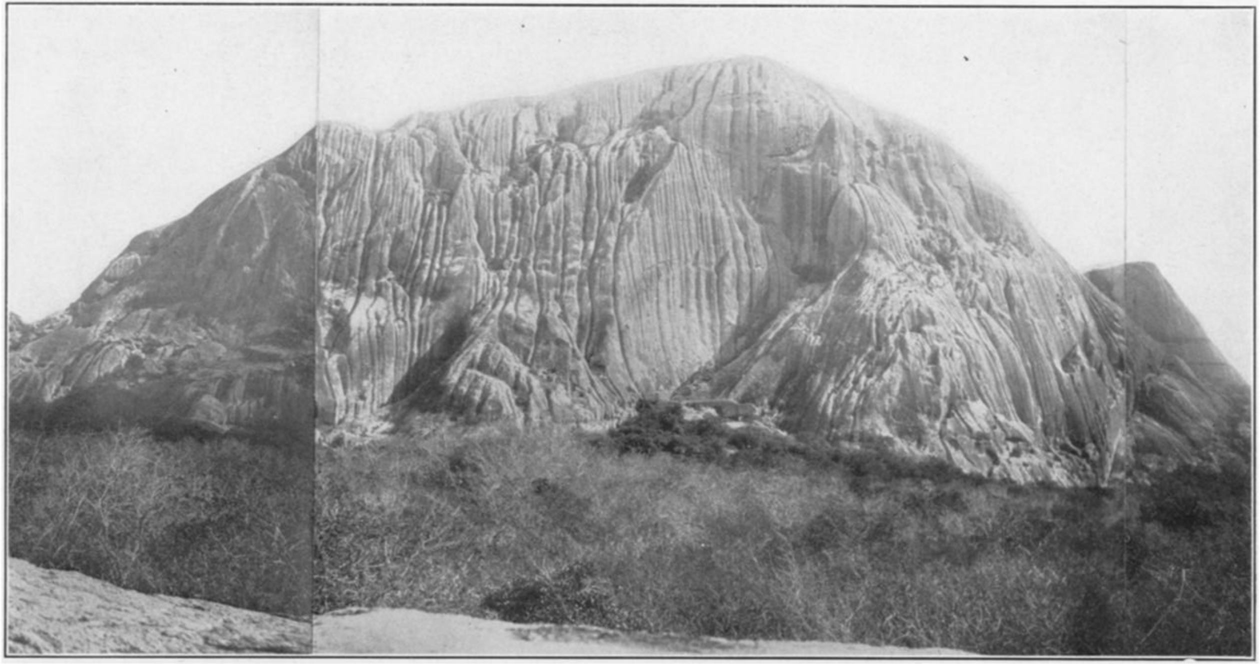
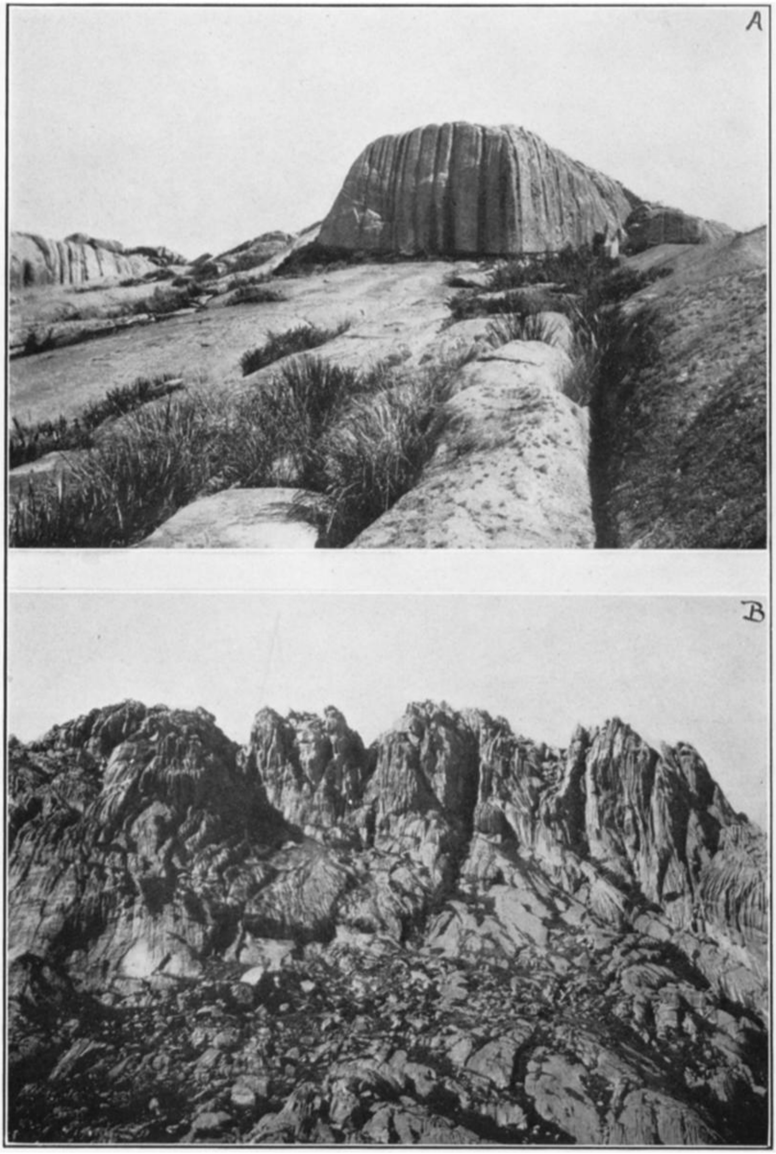
[3] *Bul. Geol. Soc. Amer.*, VII., 280, footnote.



Serra Riscada near Quixadá, Estado do Clará, Brazil. Height of the hill above its base, 226 meters. Inspectoria de Obras Contra as Seccas, phot., 1911.



Fluted syenite on and about the summit of Itatiáya, State of Rio de Janeiro, Brazil. Carlos Moreira, phot.

the miniature watersheds characteristic sharp, but somewhat ragged, combs of the rock. Between these divides are narrow, round-bottomed furrows or grooves that run down the slopes of the rocks by the shortest routes. These shallow grooves suggest the marks made by the fingers when drawn across a mass of plastic clay or putty. The furrows or grooves in limestone, however, are, as a rule, only an inch or so in diameter; that is the fluting of limestones is not usually on a large scale.

The illustrations given in Dr. Stille's "Geologische Charakterbilder," Heft 10, however, show flutings in limestones of various kinds, and some of these have unusually large furrows.

The fluting of granites and other coarsely crystalline rocks, however, is on a large scale, and the grooves have only a remote resemblance to those on limestone surfaces. The fluted surfaces necessarily appear only where the rock is entirely bare of soil. For the most part the furrows start at the summit of the exposed rock or as near it as possible, and run straight down the rock slopes by the shortest possible routes. Those seen at and about Quixadá reach a maximum depth of nearly two meters measured at right angles to the general surface of the rock masses. This takes no account of the ordinary gullies cut by the larger streams. Instead of having sharp combs separating the drainage areas of the different furrows, the divides or miniature watersheds on the granite surfaces are always rounded. But while the surfaces of the granite rocks are rounded in general outline, they are quite rough, this roughness being caused by the coarse crystals standing out boldly over the entire exposed rock surface. About Quixadá the rocks contain but little quartz, and feldspars are the minerals that produce this roughness of surface.

Caldron-like Pits.

In the Quixadá region the fluted rocks are covered here and there with great rounded caldron-like pits some of which are associated directly or indirectly with the fluting. These pits are shown in some of the accompanying illustrations (Plates III., IV., V.). They are not usually very deep, that is, they seldom exceed a depth of two meters when isolated, and they reach a diameter of two meters or more, though they are generally not so wide. The fluting sometimes has the appearance of originating in these caldrons, but this seems to be due to the water overflowing and cutting notches in the rims on one side and thus merging the pits and the fluting into each other. In some cases I have seen a series of these pits in a nearly vertical row

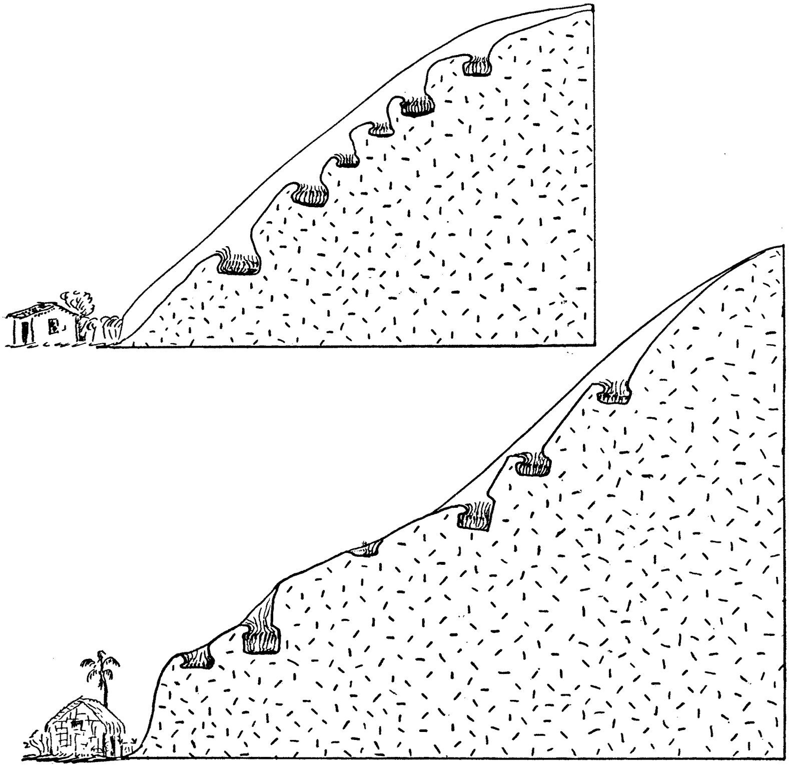
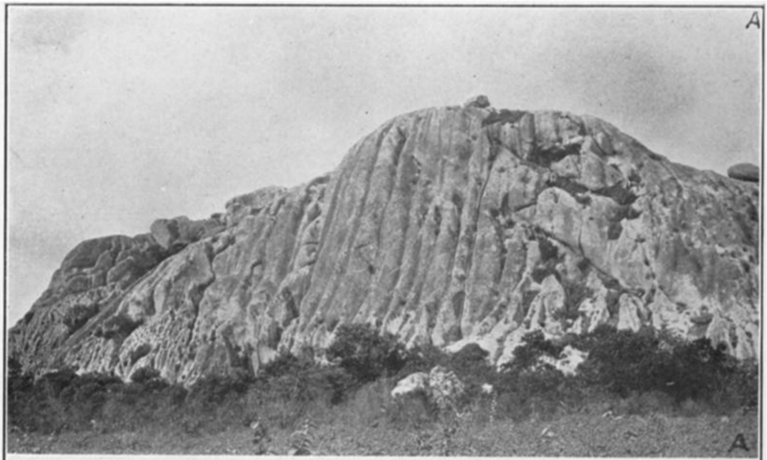
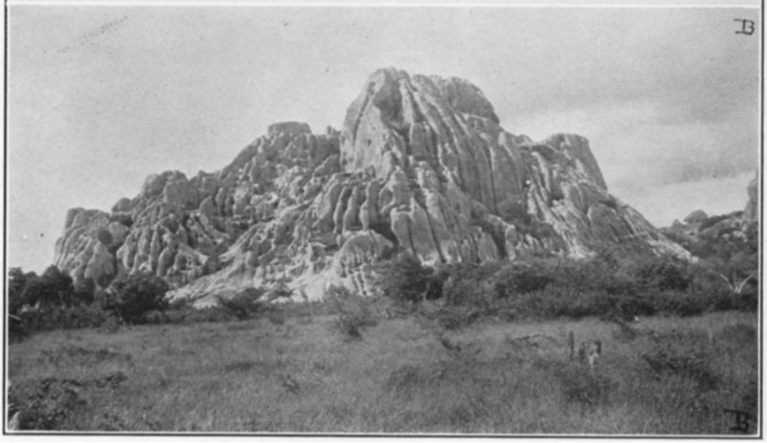


FIG. 1. Composite sections down the pitted and fluted rock surfaces at and about Quixadá showing the general forms of the caldrons.

and connected by a furrow that gives the whole the appearance of a great irregular staircase mounting the hill (Fig. 1).

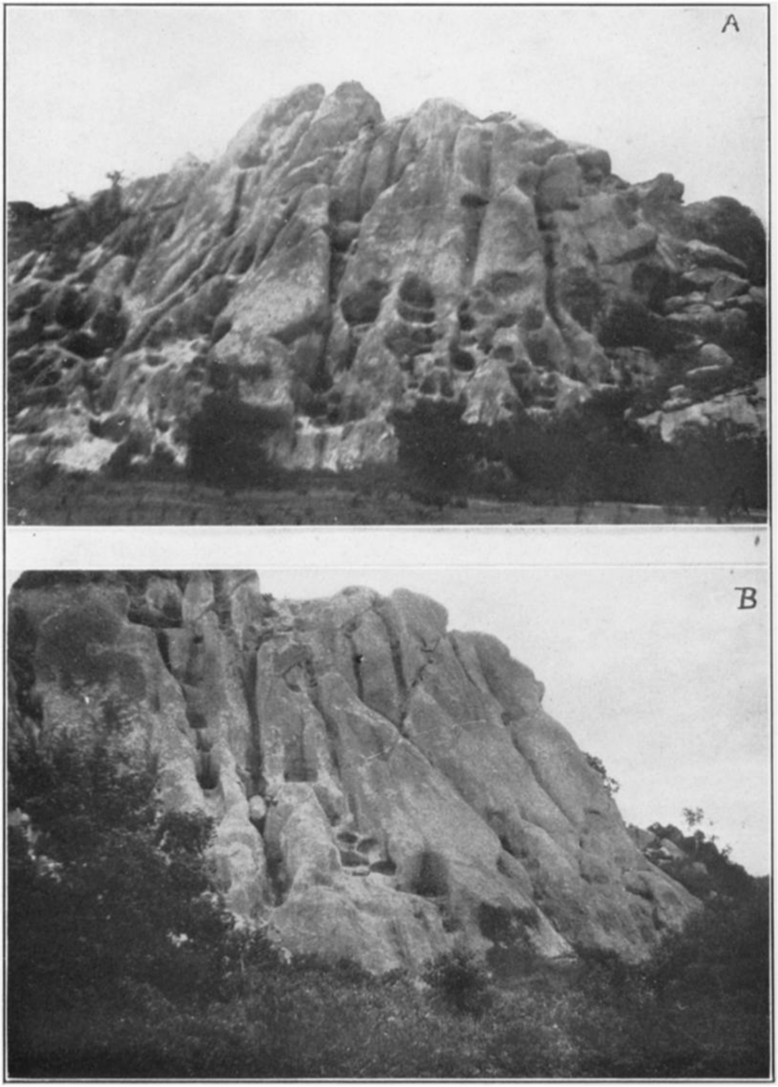
These caldrons are very abundant in some of the rocks, while in others they do not appear at all. They occur on the tops of mountains, hills, or bosses, on the sides and at the bases; they are mostly





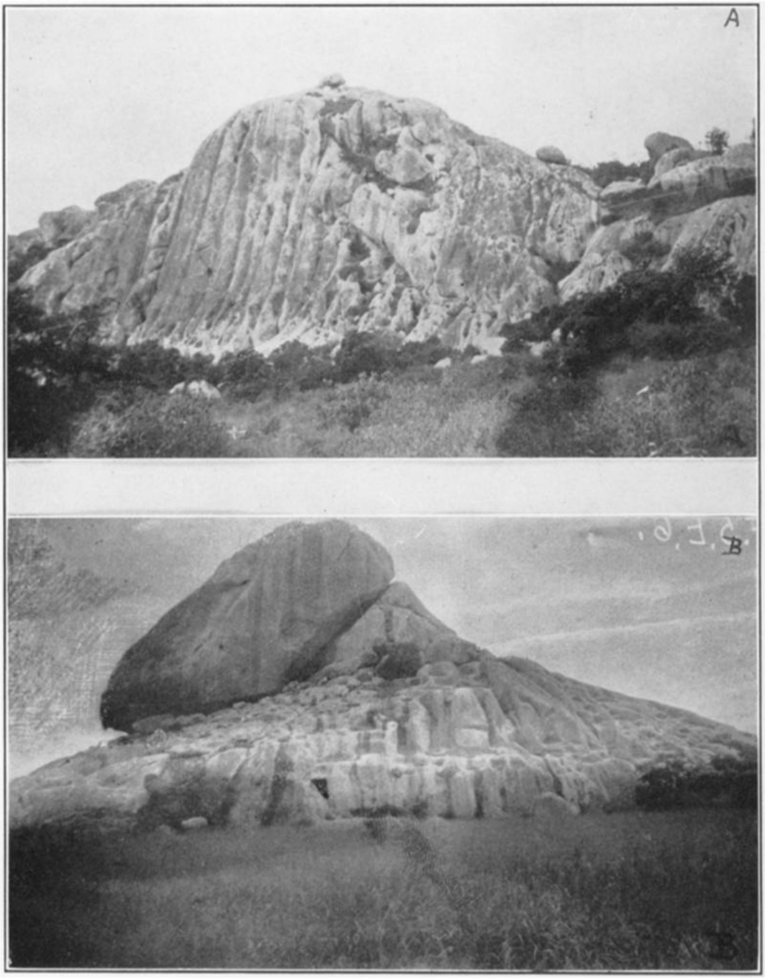
A. Fluted and pitted hills at kilometer 183, near Quixadá, Ceará. Waring, phot., 1912.

B. Fluted and pitted hills at kilometer 183½, near Quixadá, Ceará. Waring, phot., 1912.



A. Pitted syenite east of the railway near Quixadá, Ceará. Waring, phot., 1912.

B. Pitted granodiorite near Quixadá. E. Leib, phot., 1911.



A. Fluted and pitted granodiorite near Quixadá, Ceará. E. Leib, phot., 1911.

B. Pitted granite between the stations of Junco and Quixadá. E. Leib, phot., 1911.

vertical or nearly so, but some of them are also nearly horizontal. At Quixadá they are more abundant on the gentler slopes and especially about the bases of the hills. In Plate V., Fig. *B*, for example, there is a striking difference between the fluted surface in the upper part of the hill and the pitted and fluted surface of the rock about the base of it.

The great rock in the edge of the village of Quixadá is a striking illustration of the combination of pits and of fluting, though the caldrons are the more marked feature of this particular mass (Plate VI., Fig. *B*). The photographs of Itatiáya show the surface to be pitted here and there, but the pits appear to be formed on vertical walls as well as on sloping or flat surfaces (Plate VII., Figs. *B, C*).

A good deal has been made of pits or pot-holes in the granites in other parts of Brazil. In Hartt's "Geology and Physical Geography of Brazil," at pages 314–315, is an account of holes observed in granites in the interior of the state of Bahia. Following are the notes of J. A. Allen on the region southeast of the Serra de Jacobina.

> "At frequent intervals there were singular holes in the rocks, usually nearly filled with water, to which the inhabitants give the name 'caldeirões.' These 'caldeirões' are of frequent occurrence, but I was unable to learn whether all were of a similar character. Nearly all of the considerable number examined proved to be genuine pot-holes, and some of them were of great size. The largest one I measured was elliptical in outline, eighteen feet long, nine or ten in width, and twenty-seven deep, with smoothly worn sides. Beneath the water that partially filled it there must have been many feet of materials that for ages have been falling into it, so that its whole depth must be much greater than my measurements indicate."

Professor Hartt adds the following as a footnote:

> "Mr. Allen tells me that these pot-holes often occur out on the plain, far away from any high land, and that they are sometimes found excavated in the summits of slight bulgings in the plain, or even on the top of a hill, as in the case of the Morro do Caldeirão. These holes must have been excavated by falling water. There is only one suggestion that I can make as to their origin, and that is that they were formed by glacial waterfalls, in the same way as the pot-holes found over the glaciated regions of North America, as, for instance, in New Brunswick and Nova Scotia, where I have had an opportunity of examining them. It is well known that glacial waterfalls, notwithstanding the constant movement of the ice, are very often stationary, and

in the Alps they hollow out enormous pot-holes in the rocks. The lake plain is noted for the small amount of decomposition which has taken place over it, owing, I believe, largely to the fact that it has never been covered by the virgin forest, having always been dry."

The explanation here suggested will be referred to later.

Character of the Fluted and Pitted Rocks.

The fluting of crystalline rocks is not confined to any one particular kind of rock, as was at first supposed, except that they are all massive and homogeneous. Those about Quixadá in Ceará vary somewhat, but they are mostly massive coarse grained, gneissoid granodiorites, and the weathered surfaces, though rounded in outline, are very rough, owing to the feldspar crystals standing out over them in high relief.

The rocks are often more or less jointed, and the joints necessarily interfere with the regularity and extent of the fluting, though they do not prevent it. Possibly abundant jointing may so interfere with fluting as to render it quite inconspicuous.

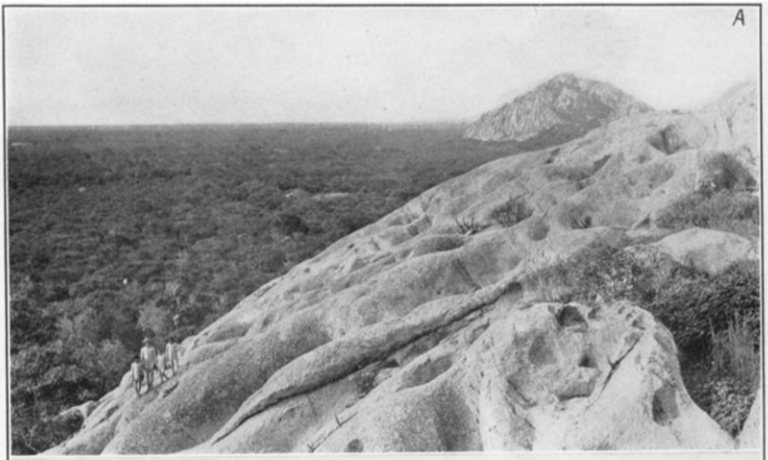
The fluted rocks of the Itatiáya group are massive homogeneous, coarse grained syenites, somewhat jointed, the joint planes having various angles with the horizons, as may be seen in the accompanying illustrations. The Itatiáya syenite is not as coarse grained, however, as the granodiorite of Quixadá.

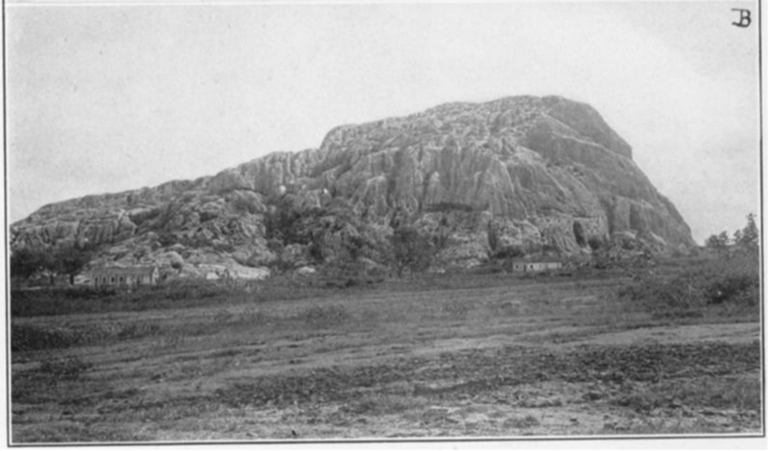
The fluting mentioned by Bauer in the Seychelle Islands is said to be in granite. The examples seen by the writer in the state of Pernambuco are all in granites.

Origin of the Fluting.

It was supposed at the outset that chemical action over openly exposed surfaces would turn out to be an important factor in the production of the fluted forms. But it does not appear that such action is especially important. It is evident that the rocks are chemically affected by the alteration of the feldspars, but there is no apparent localization of that action in the case of the fluting.

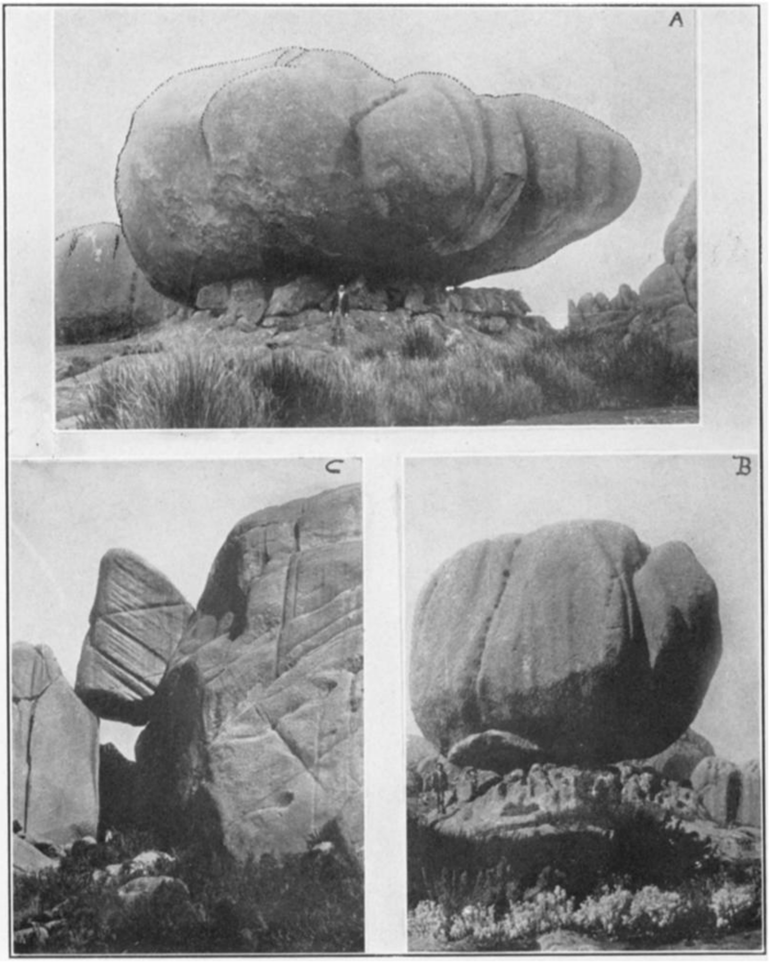
It seems most probable that in the long exposure of these homo-



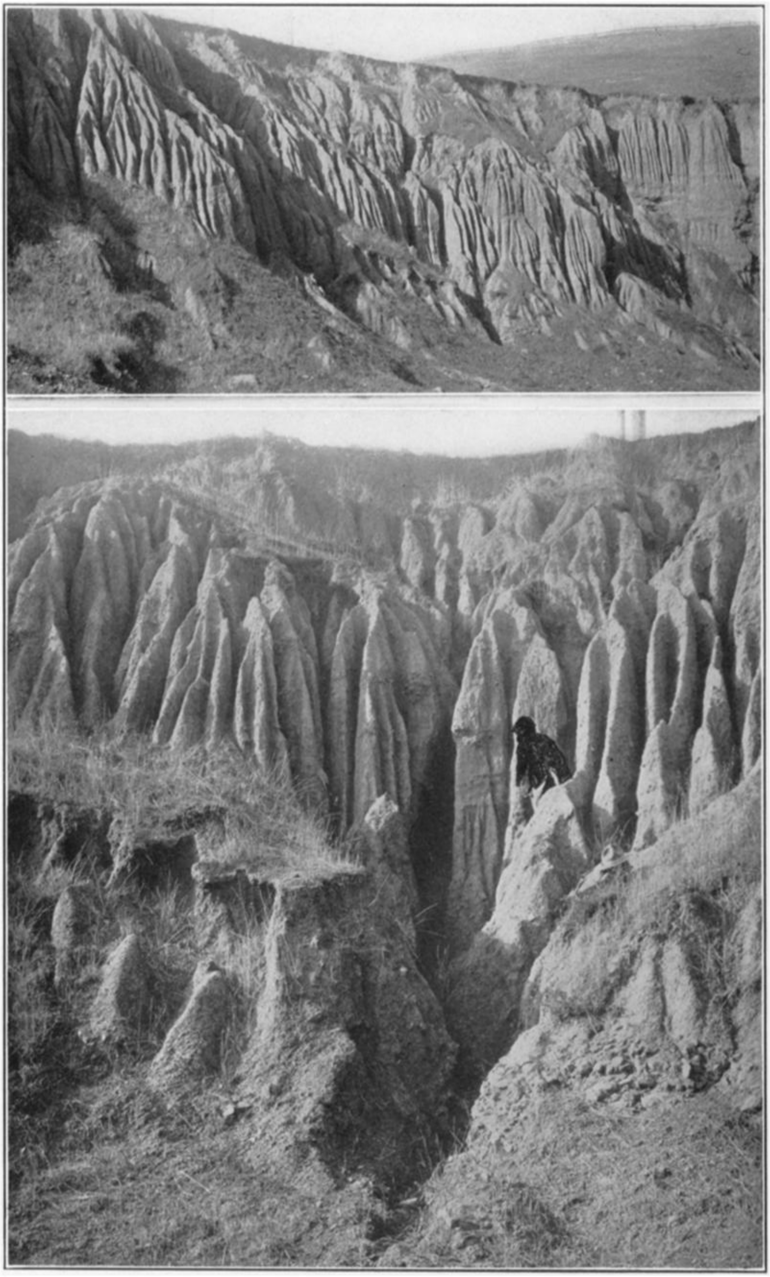


A. Top of fluted hill at kilometer 182½, near Quixadá, Ceará. Waring, phot., 1912.

B. The fluted and pitted granodiorite hill at Quixadá, Ceará. Altitude about 200 ms. Waring, phot., 1912.



Fluted boulders of decomposition in the vicinity of the peak of Itatiáya. Fig. C shows a fluted mass that has been overthrown so that the fluting is no longer vertical. Carlos Moreira, phot.



Fluted banks of sandy clay, San Bruno Mountains, south of San Francisco, Cal. Branner, 1912.

geneous rocks, the water running down the slopes sweeps along mechanically the loosened fragments of the minerals just as it would remove anything else. Channels are necessarily deepened most rapidly where most water flows, and in the process of rock removal, as a whole, the bottoms of these channels always keep in advance of the divides between them. That is, it is a narrow localization of mechanical action by water.

It is especially noticeable that the fluting is a slow process, and this slowness is explained by the fact that each furrow is made by the little water that falls within its own narrow drainage basin.

One may occasionally see in soft sandy clays furrows very similar in form to the fluting of granites. There are some rather striking examples in the San Bruno mountains just south of the city of San Francisco in California. One of the accompanying plates (Plate VIII.) shows two photographs of these particular gullies. These photographs of gullies were made in January, 1912.

The materials of these furrowed banks are sandy clays containing angular and subangular pebbles and rock fragments—apparently soil and other products of the breaking down of the shales and sandstones of the San Bruno mountains. These materials also remind one of the stone-capped earth-columns of the Tyrol, though in the present case the stone caps are wanting.

Such earth-columns are supposed to be the work of the mechanical impact of rainwater. But most of the San Bruno furrows have the appearance of being made, not necessarily by the impact of raindrops, but by the running down of the water that falls on and over the furrowed surface.

Water flowing down from the slopes above cuts the deeper gullies in the face of the bank, but the minor trenches are supplied only by water that falls on the immediate surface.

The even spacing of these furrows is one of their striking features. This is due I presume to the fact that, owing to the rather even surface and the evenness of the water supply, there is usually nothing to enable a channel to gain on its neighbors.

THE ORIGIN OF THE CALDRONS.

The suggestion of Hartt quoted on a preceding page in regard to the glacial origin of caldrons or pot-holes in the interior of Bahia must be set aside as quite out of the question, either for the ones in Ceará or for those in Bahia.[4] There is absolutely no evidence of Pleistocene glaciation in Brazil.[5] The pot-holes mentioned by Hartt and Allen in the interior of Bahia, in every case with which I am acquainted, have been cleaned out by man for the purpose of using them for water storage in times of drouth. They have but little in common with the caldrons referred to in this paper.

The Quixadá pits are in process of development, and they are evidently therefore to be explained by agencies now in operation. Aside from the openly exposed bare surface of a coarsely crystalline homogeneous rock, the factors that enter into the problem appear to be: The slope of the surface, the localization of incipient depressions, disintegration and chemical alteration of the rock forming minerals by the action of rainwater aided by organic and other acids, the concentration of rainfall, and the mechanical floating away of the disintegrated and finely divided minerals.

It seems probable that the original location of the incipient caldrons is purely accidental. Once begun, however, the standing water attacks the constituent minerals of the rock in the bottom of the pit. It is quite noticeable that in the great majority of the caldrons, perhaps in all of them, the walls are somewhat overhanging. This overhanging is due to the fact that once a pit is started, the water standing in it tends to moisten and affect a widening surface.

As soon as a depression is deep enough to retain some of the rainwater, plants begin to grow in it, and insects are drowned in it, and as these things decompose the organic acids thus produced enable the water to attack the minerals more readily.

The concentration of the rainfall of the region causes the pits to be filled with water for only a part of the time. The rest of the time the pits are dry or they are only moist on the bottom.

It has been suggested that deflation may be an agency in the formation of these caldrons. In my opinion deflation may be important in the early stages of excavation, when the depth does not prevent the wind from blowing away small loose fragments of the minerals, but when a pit is a meter or more in depth and a meter in width it seems highly improbable that the wind is a factor of any importance in the direct removal of materials, though it may be indirectly important enough in the bringing of plant seeds or spores.

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[4] Hartt's "Geology and Physical Geography of Brazil," pp. 314–315.

[5] "The Supposed Glaciation of Brazil," *Jour. Geol.*, I., 753–772.

The things that seem to me competent to account for the removal of the disintegrated minerals are suggested by the dark lines that run down the rocks from the notches in the lips of all of the caldrons. These dark streaks are made by overflowing water.

When water stands for some time in the pits it becomes covered by low forms of plant life, apparently freshwater algæ for the most part. When in time the water dries up this material is left spread over the bottom where it packs together, a sticky fibrous mass clinging to and closely enwrapping whatever lies in the bottom of the pit. In time the rains come again and the pit is filled to overflowing, the matted masses of algæ are floated to the top and carried over the edge of the caldron, taking with them some of the mineral fragments from the bottom of the pit. The rapid growth of vegetation in such waters is greatly facilitated by the hot climate, while the hot dry air and the high winds quickly dry up the waters when once the pits are filled by the rains. The peculiar concentration of the rainfall at Quixadá likewise hastens this natural process of excavation.

Still more important in most instances is the stirring of the materials in the bottoms of the caldrons by the inflowing water. The mud in the bottom being thus stirred by the water pouring in, a great deal of the finer material is carried out when the pit is full and overflows its lower lip. It must not be supposed, however, that the water flowing into the caldrons is of sufficient volume to whirl the coarse materials and thus grind out the rock. This is far from being the case. I found no evidence of any such mechanical wear on the insides of the pits. They are all uniformly rough within.

When the pits are shallow, however, and are so far down the slopes that the water enters them with a rush it is readily imagined that all or most of the finer materials must be swept over the rim. Some of the forms suggest that old and deep caldrons have from time to time been obliterated by the breaking down of their lower lips.

Fortunately we have the records of the rainfall taken at Quixadá from 1891 to 1906.[6] These records show that during those fifteen years the total precipitation was 10,711 millimeters. Distributed by months, the greatest rainfall was in February, March, April, and May when it reached an average of 134 millimeters a month; the minimum fell in August, September, October, and November with an average of 17 millimeters per month.

These figures taken alone, however, do not give a clear idea of the climatic conditions in the semi-arid region about Quixadá. An important fact that bears directly upon the question of the origin of these caldrons is that the rains are frequently torrential while they last, even during the dry season, and that they are often followed by periods of drouth during which the hot dry atmosphere quickly takes up the water filling the caldrons. For example, the table of rainfall shows that in October, 1894, there was a precipitation at Quixadá of 96 millimeters in a single day, and that too in the dry season. In December of the same year 95 millimeters fell in two days; in July, 1904, the rainfall was 147 millimeters in two days. In the last case this heavy rain was followed by nearly five months of complete drouth. But even in the absence of long drouths, the rapid evaporation and high winds and high temperatures would empty one of these caldrons in a short time. The temperature at Quixadá[7] in 1897 ranged from an absolute maximum of 36.2° C. to an absolute minimum of 22.1° C.

Statistics dating back to 1711 bear out the generally accepted fact that the interior of Ceará is a region of frequent drouths. In the 189 years from 1711 down to and including the year 1900 it is claimed that there have been thirty-one years of drouth.[8] But even the years of drouth may have had rain enough to overflow the caldrons several times without there being enough to answer the purposes of the planters and cattle growers.

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[6] Thomaz Pompeo de Souza Brasil, "O Ceará no começo do Seculo XX.," Fortaleza, 1909, p. 330.

[7] F. M. Draenert, "Zum Klima des Staates Ceará, Brasilien," *Meteorologische Zeitschrift,* April, 1903.

[8] Raymundo Pereira da Silva, "O Problema do Norte." Rio de Janeiro. 1907, p. 7.

It may be worth noting also that in dry seasons, and as long as the water lasts, birds and other animals flock to these caldrons to drink.

The total result of the alternation of rain and drouth must be a frequent filling and emptying of the pits, a frequent stirring up of the fine materials in the bottoms of the pits, and its removal in mechanical suspension by the water overflowing the lips of the caldrons.

These facts also suggest why the caldrons are most abundant about the lower slopes rather than on the crests of the hills: there is a larger run-off, and consequently a more frequent and a more vigorous disturbance of the water in the pits.

The horizontal pits occasionally seen in vertical rock walls are evidently not made in the same way as the vertical pits formed in flat or sloping surfaces. The latter seem to be due to the alternate absorption and evaporation of water much as fret-work is formed over the surfaces of porous sandstones by the prying off of sandgrains. Some remarkable cases of this kind are known in the interior of the state of Bahia in Brazil. Instances of this sort are now being studied and no further mention of them need be made at present.

Conclusions

The fluting and pitting of coarse grained crystalline rocks appears to be confined to tropical countries, and to massive, homogeneous rocks openly exposed.

The grooves that make up the fluted surfaces run down the rock faces by the shortest possible courses, and are made by the small amount of water that falls upon and flows down the fluted surfaces themselves. In other words there are no strong streams flowing across fluted surfaces whose waters are gathered over a wide area.

Fluting seems to be confined to steep slopes. The angle of such slopes cannot be stated, but in the cases observed it usually was forty-five degrees or more.

The process of fluting is partly chemical and partly mechanical and physical. As a whole the process is necessarily a slow one. The localization of the run-off leads to an approximately even spacing of the small streams and consequently to the even spacing of the fluting where it appears over a broad surface. Somewhat similar erosion forms are to be seen occasionally in homogeneous sandy clays, though owing to the character of the materials the latter are cut rapidly.

Though fluting seems to be confined to tropical countries, it is worth noting that the temperature on the Serra do Itatiáya in Brazil, where fluting is very marked, often falls below freezing. Evidently some freezing does not interfere with fluting.

Caldron-like pits are associated with fluting, and occur chiefly on slopes not so steep as the fluted ones. They are most abundant on the lower parts of the bare rock surfaces. They are formed by water dissolving and disintegrating the minerals, and by the inflowing waters mechanically stirring and floating the finer particles over the rims of the basins. The chemical action of the water in the pits is hastened by the decay of plants and other organisms that live and die in the water left standing in the pits by the rain.

Exfoliation is not a prominent feature of the fluted and pitted masses. Indeed exfoliation hardly occurs at all in such places. Disintegration goes on rapidly, but it attacks the entire surface pretty evenly. The feldspars seem to resist weathering better than the accompanying minerals, at least the feldspars are left standing out in high relief over these surfaces. In time the mere heating and cooling of the feldspars breaks them up, and they are washed off by the torrential tropical rains as angular fragments or they are blown off by the winds.

The absence of talus about the bases of these fluted and pitted hills is very striking. Indeed there are quite as many boulders on the summits and sides of the hills as there are about their bases. This seems to be due to the even attack of disintegration over all surfaces, and to the fact that there is no freezing and thawing to chip off the upper surfaces of hills and rocks and to pile up the fragments at the bases of the slopes.

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